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**RSRM-7 (360L007) FINAL REPORT
BALLISTICS/MASS PROPERTIES**

20 December 1989

Prepared for:

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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MORTON THIOKOL, INC.

Aerospace Group

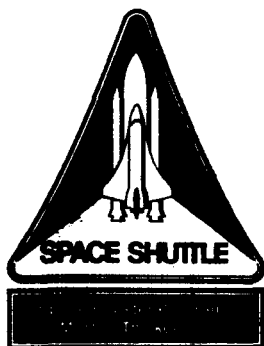
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BALLISTICS MASS PROPERTIES

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1.0 INTRODUCTION

This report contains the propulsion performance and reconstructed mass properties data from Thiokol's RSRM-7 motors which were assigned to the STS-33 launch. The Thiokol manufacturing designations for the motors were 360L007A/360L007B, which are referred to in this report as RSRM-7A and RSRM-7B, respectively. The launch occurred on 22 November 1989 at the Eastern Test Range (ETR). The data contained herein was input to the STS-33R Flight Evaluation Report.

The SRM propellant, TP-H1148, is a composite type solid propellant, formulated of polybutadiene acrylic acid acrylonitrile terpolymer binder (PBAN), epoxy curing agent, ammonium perchlorate oxidizer and aluminum powder fuel. A small amount of burning rate catalyst (iron oxide) was added to achieve the desired propellant burn rate. The propellant evaluation and raw material information for the RSRM-7 are included in the discussion section of this report.

The propellant grain design consists of four segments. There is a forward segment with an eleven point star with a transition into a tapered circular perforated (CP) configuration. There are two center segments that result in a double tapered CP configuration and an aft segment with a triple taper CP configuration and a cutout for the partially submerged nozzle (Figure 1.1).

The ballistic performance presented in this report was based on the Operational Flight Instrumentation (OFI) 12.5 sample per second pressure data for the steady state and tail off portion of the pressure trace. The 12.5 s/sec OFI data on the right motor was adjusted down by 0.4 percent to closer match the other right motor OFI gauges. The OFI data on the left motor needed no adjustment. In addition, the data for both motors was adjusted up by 1% from 0 to 1 seconds and then ramped down from 1.0% to 0.4% from 1-2 seconds and then adjusted up 0.4% thereafter. These adjustments are a result of a bias between the OPT and Taber pressure transducers which are used on flights and static tests respectively. No high sample rate pressure gauges, Development Flight Instrumentation (DFI), were used on this flight and therefore no ignition data will be presented.

2.0 SUMMARY

The delivered propellant burn rates were close to predicted. The delivered burn rates were 0.365 in/sec at 625 psia and 60°F for the left RSRM and 0.367 for the right. The predicted burn rates were 0.365 in/sec for both the left and right motors. The average of the two motors was 0.002 in/sec below the target rate of 0.368 in/sec at 625 psia and 60°F. The performance of the two motors were very close to the same as can be seen in Figure 2.1.

The performance of the pair of motors were compared to the following CEI Specification CPW1-3600A paragraphs for compliance: 3.2.1 Performance, 3.2.1.1 General Performance, 3.2.1.1.2 Motor Characteristics, 3.2.1.1.2.1 Nominal Thrust Time Curve, 3.2.1.1.2.2 Performance Tolerance and Limits, 3.2.1.1.2.4. Impulse Gates and 3.2.1.1.2.3 Thrust Differential. The aspects of the CEI Specification that could not be compared due to low sampling of the data were 3.2.1.1.1 Ignition Characteristics, 3.2.1.1.1.1 Ignition Interval and 3.2.1.1.1.2 Pressure Rise Rate. The performance from each motor as well as matched pair performance values were well within the CEI Specification requirements. The nominal thrust time curve and impulse gate information has been included. The historical average was well within the variation limits developed from the HPM Block prediction population at a burn rate of 0.368 in/sec at 625 psia and 60°F. The historical population values are the average performance data from QM-4, SRM-8, SRM-9A, SRM-10, SRM-11A, SRM-12 through SRM-19, SRM-24, ETM-1A, DM-8, DM-9, QM-6, QM-7, PVM-1, RSRM-1, RSRM-2, RSRM-3, RSRM-4A, RSRM-5, RSRM-6, and RSRM-7.

Post flight reconstructed RSRM mass properties are within expected values for the RSRM lightweight (RSRML) configurations and meet the following CEI paragraphs: 3.2.2.2, 3.2.2.2.1, 3.2.2.2.2, and 3.2.2.2.3.

3.0 DISCUSSION AND RESULTS

3.1 RSRM-7 PROPELLANT MATERIALS

Both of the seventh flight motors were cast with primarily one evaluation of propellant, E67. An evaluation is defined as a specific combination of raw material lots and all of the standardization and production batches of propellant produced with these materials. There were however 2 verification mixes of evaluation E69 in the right motor forward center segments, and 2 in the right aft center segment. Table 3.1 shows the raw material lots and vendors for the evaluations used. The igniters used in this flight set were cast from propellant evaluation F70, mix F700003. See document TWR-19063 for more information on propellant materials for this flight set. For more information on this lot of igniters see lot acceptance test (LAT) 40 test report (TWR-18600).

3.2 RSRM PROPULSION PERFORMANCE ANALYSIS

All times shown in this section, unless noted otherwise are referenced to the RSRM ignition command time at 89:327:00:23:30:000(GMT).

As previously mentioned the OFI (12.5 s/s) data was used for the steady state and tail off performance assessment.

The ballistic performance was reconstructed using SCB04 steady state 1-D mass addition computer program, and SCA08 SRM modeling program. Both computer codes have been consistently used for predictions as well as reconstructions throughout the SRM program. Since thrust was not measured on the flight motors, average values of η_T 's and C_m 's, which are used for the pressure to thrust conversion, were taken from RSRM static test motors and applied to the measured head end pressure to determine the thrust values.

3.3 RSRM DELIVERED PERFORMANCE

3.3.1 RSRM-7A/RSRM-7B Thrust and Pressure Comparison

The flight motor reconstructed thrust-time traces at the delivered temperature of 71°F are shown in Figure 2.1. A comparison between the predicted thrust and reconstructed thrust for each motor can be seen in Figures 3.1, 3.2.

The comparison of predicted and measured head end chamber pressure is shown in Figures 3.3, 3.4.

Figures 3.5 and 3.6 show how RSRM-7A and RSRM-7B compared with a nominal performance average for the RSRM at standard conditions of 0.368

burn rate and 60 °F PMBT. From the figures, it is evident that the RSRM design will continue to influence the shape of the average thrust time trace near 50 seconds.

3.3.2 RSRM Predicted Impulse, ISP, Burn Rate, Event Times, Separation, and PMBT Comparison

The reconstructed RSRM-7 propulsion performance at delivered conditions is compared to the predicted performance in Table 3.2. The actual values are very close to the predicted data for both motors.

The predicted scale factor of 1.0175 for conversions from 5 inch CP burn rates to actual motor burn rate were based on an average scale factor from the HPM-RSRM population. The actual scale factors for left and right motors were 1.0162 and 1.0216 respectively.

The propellant mean bulk temperature (PMBT) used in the Ballistics reconstruction for both motors was 71°F. This was based on predicted 2-D temperature gradients expected in the RSRMs. Table 3.3 shows the predicted gradient (data provided by 2-D SINDA Model Aero-Thermal Group).

3.4 CEI SPECIFICATION PERFORMANCE REQUIREMENTS

3.4.1 Performance Tolerances

The parameter variations of the total population of RSRMs about a nominal value are constrained by the requirements defined in the CEI Specification paragraph 3.2.1.1.2.2, Table II. A comparison of the RSRM-7A and RSRM-7B calculated and reconstructed parameters at PMBT of 60°F with respect to the nominal values and the CEI Specification maximum 3 sigma requirements is shown in Tables 3.4 and 3.5. All values are within CEI specification requirements.

3.4.2 RSRM Nominal Thrust-Time Performance

The nominal RSRM-HPM performance is defined as the average performance of the HPM and RSRM static test and flight motor series at standard conditions. The standard conditions consist of the propellant burn rate of 0.368 in/sec at 625 psia and a PMBT of 60°F. The flight motor reconstructed thrust-time traces are normalized to standard conditions and averaged with past flight and static test data at standard conditions to form the RSRM-HPM population nominal thrust-time trace. This nominal RSRM-HPM performance will be continually updated during the Shuttle program. It is the current estimate of the total population nominal. The nominal performance for the thrust time trace and impulse gate requirements is based on the performance of QM-4, SRM-8, SRM-9A, SRM-10, SRM-11A, SRM-12 through SRM-19, SRM-24, ETM-1A, DM-8, DM-9, QM-6, QM-7, PVM-1, RSRM-1, RSRM-2, RSRM-3, RSRM-4A, RSRM-5, RSRM-6, and RSRM-7. The delivered RSRM-HPM population nominal performance is compared to the CEI Specification paragraph 3.2.1.1.2.1, Table I requirements on Figure 3.7.

3.4.3 Impulse at Standard Conditions VS. Requirement Gates

The vacuum impulse at standard conditions at each of the gates is compared to the CEI Specification paragraph 3.2.1.1.2.4 requirements in Table 3.6. The population making up the standard nominal for the impulse requirements are the same as those in the nominal thrust time trace (Figure 3.7).

3.4.4 Matched Pair Thrust Differential

The maximum thrust imbalance assessment is shown in Table 3.7. Figure 3.8 through Figure 3.10 shows the thrust differential during steady state and tail off. All the thrust differential values were near the nominal values experienced by previous flight SRMs and were well within the CEI Specification paragraph 3.2.1.1.2.3, Table III limits. The thrust values used for the assessment were reconstructed at the delivered conditions of each motor.

3.4.5 Matched Pair Performance Requirements

The CEI Specification requires that a matched pair of motors on a flight set have similar performance at delivered conditions according to Table 3.8. The RSRMs for STS-33 were well within the matched pair specification requirements.

3.5 RECONSTRUCTED MASS PROPERTIES

The Thiokol manufacturing designation, 360L007, along with STS-33 have been used, by Mass Properties, to identify the RSRMs used on this flight. Tables 3.9 and 3.10 provide STS-33A and STS-33B reconstructed sequential mass properties, respectively.

Table 3.11 and 3.12 compares RSRML predicted sequential weight and center of gravity (cg) data against post flight reconstructed data. A 2,000 lbm slag weight was used for both pre-fire and post-fire sequential predictions. Actual STS-33 mass properties may be obtained from Mass Properties History Log Space Shuttle 360L007-LH (TWR-17346), dated 5 August 1989, and 360L007-RH (TWR-17347), dated 5 August 1989. Some of the mass properties data used has been taken from average actual data presented in the 5 June 1989 Mass Properties Quarterly Status Report(TWR-10211-91). Postflight reconstructed data reflects Ballistics mass flow data from the 12.5 sample per second measured pressure traces and a predicted slag weight of 2,000 lbm.

Table 3.13 and 3.14 presents CEI requirements, predicted, and actual weight comparisons. The actual weights are in close agreement with predicted values. Mass Properties data for both RSRMs comply with CEI requirements.

TABLE 3.1
RAW MATERIAL EVALUATION SUMMARY

TP-H1148 PROPELLANT EVALUATION	INGREDIENT	STOCK-LOT	VENDOR
E67	HB Polymer ECA Aluminum Iron Oxide AP unground AP ground HB/ECA Ratio Iron Oxide	7227-0071 7225-0079 7228-0068 7226-0017 7229-0078 7229-0078 87.0% HB 0.250%	ASRC Dow Chemical Alcoa Charles Pfizer Kerr McGee Kerr McGee
E69V	HB Polymer ECA Aluminum Iron Oxide AP unground AP ground HB/ECA Ratio Iron Oxide	7227-0073 7225-0081 7228-0070 7226-0016 7229-0080 7229-0080 86.7% HB 0.243%	ASRC Dow Chemical Alcoa Charles Pfizer Kerr McGee Kerr McGee

TABLE 3.2 RSRM-7 PROPULSION PERFORMANCE ASSESSMENT

	(LEFT MOTOR 71 DEG)		(RIGHT MOTOR 71 DEG)	
	PREDICTED	ACTUAL	PREDICTED	ACTUAL
IMPULSE GATES				
I-20 (10 ⁻⁶ lbf sec)	65.00	64.78	64.99	65.18
I-60 (10 ⁻⁶ lbf sec)	173.59	173.11	173.58	173.36
I-AT (10 ⁻⁶ lbf sec)	297.14	296.75	297.14	296.04
VACUUM ISP (lbf*sec/lbm)	268.5	268.2	268.5	267.6
BURN RATE (in/sec @ 625 psia)	0.3684	0.3677	0.3684	0.3693
EVENT TIMES (sec) *				
IGNITION INTERVAL	0.232	N/A	0.232	N/A
WEB TIME *	110.9	111.1	110.9	111.0
TIME OF 50 PSIA CUE	120.8	121.3	120.8	120.2
ACTION TIME *	122.9	123.4	122.9	122.9
SEPARATION COMMAND (sec)	125.7	126.2	125.7	126.2
PMBT (deg F)	73.0	71.0	73.0	71.0
MAXIMUM IGNITION RISE RATE (psia/10 ms)	91.9	N/A	91.9	N/A
DECAY TIME (sec) (59.4 psia to 85 K)	2.8	2.8	2.8	3.4
TAILOFF IMBALANCE IMPULSE DIFFERENTIAL (KLBF-SEC)	PREDICTED N/A		ACTUAL + 693	

Impulse Imbalance = Left Motor - Right Motor

* All times are referenced to ignition command time except where noted by an *. These times are referenced to lift off time (ignition interval).

TABLE 3.3
PREDICTED PROPELLANT
TEMPERATURE GRADIENTS IN RSRM-7

DISTANCE FROM OUTSIDE SURFACE OF CASE (IN.)	15	45	75	105	135	165	195	225	255	285	315	345
0.0 CASE SURFACE	63.11	63.21	63.77	64.58	65.61	67.08	67.38	67.77	67.90	66.91	65.19	63.81
0.25 STEEL CASE	63.12	63.21	63.78	64.60	65.62	67.09	67.40	67.78	67.91	66.92	65.20	63.81
1.094 PROPELLANT	63.79	63.90	64.52	65.42	66.47	67.93	68.33	68.70	68.82	67.79	66.02	64.49
6.114 PROPELLANT	66.06	66.18	66.84	67.78	68.83	70.20	70.64	70.98	71.06	70.04	68.31	66.74
13.130 PROPELLANT	69.75	69.83	70.38	71.17	72.07	73.17	73.59	73.89	73.91	73.07	71.62	70.32
21.550 PROPELLANT	72.51	72.55	72.97	73.61	74.33	75.15	75.53	75.78	75.75	75.10	73.98	72.97
29.970 PROPELLANT	74.06	74.08	74.41	74.93	75.54	76.17	76.50	76.71	76.64	76.12	75.24	74.44
38.390 PROPELLANT	74.78	74.79	75.07	75.53	76.06	76.58	76.89	77.06	76.99	76.53	75.79	75.12

TABLE 3.4

**COMPARISON OF RSRM-7A VARIATIONS
AT PMBT = 60°F ABOUT THE NOMINAL TO THE
CEI SPECIFICATION REQUIREMENTS**

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-7A VALUE (3)	RSRM-7A VARIATION % (4)
WEB TIME	±5.0	111.7	112.4	+0.63
ACTION TIME	±6.5	123.4	124.8	+1.13
WEB TIME AVG PRESSURE	±5.3	660.8	655.4	-0.82
MAX PRESSURE	±6.5	918.4	904.1	-1.56
MAX SEA LEVEL THRUST	±6.2	3.06	3.03	-0.98
WEB TIME AVG VAC THRUST	±5.3	2.59	2.57	-0.77
VAC DEL SPECIFIC IMPULSE	±0.7	267.1	268.1	+0.37
WEB TIME VAC TOTAL IMPULSE	±1.0	288.9	288.6	-0.10
ACTION TIME TOTAL IMPULSE	±1.0	296.3	296.4	+0.03

PRESSURE VALUES IN PSIA, THRUST VALUES IN MLBF,
IMPULSE VALUES IN MLBF-SEC
TIME VALUES IN SECONDS

- (1) CEI PARAGRAPH 3.2.1.1.2.2, TABLE II
- (2) QM-4 STATIC TEST AND SRM-8A AND B, SRM-9A, SRM-10A, SRM-10B, SRM-11A, SRM-13A AND SRM-13B FLIGHT AVERAGE AT STANDARD CONDITIONS.
- (3) RSRM-7A AT PMBT = 60°F
- (4) VARIATION = ((RSRM-7A - NOMINAL)/NOMINAL)*100

TABLE 3.5

**COMPARISON OF RSRM-7B VARIATIONS
AT PMBT = 60°F ABOUT THE NOMINAL TO THE
CEI SPECIFICATION REQUIREMENTS**

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-7B VALUE (3)	RSRM-7B VARIATION % (4)
WEB TIME	±5.0	111.7	112.3	+0.54
ACTION TIME	±6.5	123.4	124.3	+0.73
WEB TIME AVG PRESSURE	±5.3	660.8	655.6	-0.79
MAX PRESSURE	±6.5	918.4	910.7	-0.84
MAX SEA LEVEL THRUST	±6.2	3.06	3.05	-0.33
WEB TIME AVG VAC THRUST	±5.3	2.59	2.57	-0.77
VAC DEL SPECIFIC IMPULSE	±0.7	267.1	267.4	+0.11
WEB TIME VAC TOTAL IMPULSE	±1.0	288.9	288.5	-0.14
ACTION TIME TOTAL IMPULSE	±1.0	296.3	295.7	-0.20

PRESSURE VALUES IN PSIA, THRUST VALUES IN MLBF,
IMPULSE VALUES IN MLBF-SEC
TIME VALUES IN SECONDS

- (1) CEI PARAGRAPH 3.2.1.1.1, TABLE II
- (2) QM-4 STATIC TEST AND SRM-8A AND B, SRM-9A, SRM-10A, SRM-10B, SRM-11A, SRM-13A AND SRM-13B FLIGHT AVERAGE AT STANDARD CONDITIONS.
- (3) RSRM-7B AT PMBT = 60 F
- (4) VARIATION = ((RSRM-7B - NOMINAL)/NOMINAL)*100

TABLE 3.6
RSRM-HPM POPULATION
IMPULSE GATES

IMPULSE (3)	REQUIREMENT (1)	STANDARD NOMINAL (2)
Impulse at 20 sec (10**6 LBF-SEC)	63.1 (MIN)	64.6
Impulse at 60 sec (10**6 LBF-SEC)	171.2 - 178.1 172.9 (+3%,-1%)	172.8
Impulse at ACTION TIME (10**6 LBF-SEC)	293.8 (MIN)	296.7

- (1) CEI PARAGRAPH 3.2.1.1.2.4
- (2) NORMALIZED TO STANDARD CONDITIONS-BURN RATE OF 0.368 IN/SEC. POPULATION IS SAME AS USED TO COMPARE NOMINAL THRUST TRACE, Figure 3.17.
- (3) IMPULSE VALUES ARE CALCULATED FROM IGNITION.

TABLE 3.7 RSRM-7 THRUST IMBALANCE SUMMARY

EVENT	IMBALANCE SPECIFICATION (KLBF)	MAXIMUM IMBALANCE (KLBF)	TIME OF MAXIMUM IMBALANCE (SEC)
STEADY STATE (1.0 SEC TO FIRST WEB TIME MINUS 4.5 SEC, LBF, 4 SEC AVERAGE)	85	+ 29.4	106.5
TRANSITION (FIRST WEB TIME MINUS 4.5 SEC TO FIRST WEB TIME, LBF)	85 - 268 LINEAR	+ 83.0	111.0
TAILOFF (FIRST WEB TIME TO LAST ACTION TIME)	710	+ 110.3	119.6

THRUST IMBALANCE = LEFT SRM - RIGHT SRM

TABLE 3.8
MATCHED PAIR PERFORMANCE LIMITS

PARAMETER	CEI SPECIFICATION MAX DIFFERENCE(%) (1)	DELIVERED % DIFFERENCE (2)
WEB TIME	±2.0	+0.09
ACTION TIME	±3.0	+0.41
WEB TIME AVG PRESSURE	±2.0	+0.03
MAX PRESSURE	N/A	+0.81
MAX SEA LEVEL THRUST	N/A	+0.65
WEB TIME AVG VAC THRUST	±2.0	+0.00
VAC DEL SPECIFIC IMPULSE	±1.0	+0.22
WEB TIME VAC TOTAL IMPULSE	±1.4	+0.03
ACTION TIME TOTAL IMPULSE	±1.4	+0.24

PRESSURE VALUES IN PSIA, THRUST VALUES IN MLBF,
IMPULSE VALUES IN MLBF-SEC
TIME VALUES IN SECONDS

- (1) CEI SPECIFICATION PARAGRAPH 3.2.1.1.2.2, TABLE II
- (2) DIFFERENCE = ((RSRM-7B - RSRM-7A)/RSRM-7 AVERAGE)*100
DATA AT PMBT OF 71 DEG F

TABLE 3.9
STS-33 LH SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY		MOMENT OF INERTIA		
		LONG.	LAT.	VERT.	PITCH	ROLL YAW
PRE-LAUNCH TIME = 0.00	1256048.8	1171.216	0.059	0.006	42399.784	879.679 42400.661
LIFT-OFF TIME = 0.23	1255355.9	1171.348	0.059	0.006	42356.568	878.307 42357.445
INTERMEDIATE BURN TIME = 20.00	1015275.1	1207.838	0.073	0.008	30751.911	762.178 30752.785
INTERMEDIATE BURN TIME = 40.00	794930.3	1231.315	0.093	0.010	21742.171	628.000 21743.039
MAX "Q" TIME = 54.00	665382.3	1229.061	0.110	0.011	18059.498	551.070 18060.360
INTERMEDIATE BURN TIME = 60.00	610938.0	1226.654	0.120	0.012	16674.024	516.028 16674.883
INTERMEDIATE BURN TIME = 80.00	420824.4	1214.945	0.172	0.018	12032.106	382.862 12032.954
MAX "G" TIME = 87.00	356709.3	1213.710	0.203	0.021	10637.140	332.405 10637.983
INTERMEDIATE BURN TIME = 100.00	251484.4	1225.613	0.286	0.030	8636.771	244.152 8637.606
WEB BURN TIME = 111.32	175040.2	1266.063	0.408	0.043	7328.101	174.248 7328.929
END OF ACTION TIME TIME = 123.66	144580.9	1315.655	0.492	0.053	6606.016	146.915 6606.839
SEPARATION TIME = 126.20	143975.4	1317.334	0.495	0.053	6575.401	146.494 6576.228
MAX REENTRY "Q" TIME = 321.20	143568.3	1317.337	0.496	0.052	6554.871	146.134 6555.698
NOSE CAP DEPLOYMENT TIME = 351.20	143516.0	1317.319	0.496	0.052	6552.099	146.088 6552.926
DROGUE CHUTE DEPLOYMENT TIME = 351.80	143515.0	1317.319	0.496	0.052	6552.044	146.087 6552.870
FRUSTUM RELEASE TIME = 372.90	143478.2	1317.306	0.496	0.052	6550.080	146.054 6550.907
MAIN CHUTE LINE STRETCH TIME = 374.20	143475.9	1317.306	0.496	0.052	6549.959	146.052 6550.787
MAIN CHUTE 1ST DISREEFING TIME = 384.30	143458.3	1317.300	0.496	0.052	6549.016	146.037 6549.843
MAIN CHUTE 2ND DISREEFING TIME = 390.20	143448.1	1317.297	0.496	0.052	6548.463	146.028 6549.290
NOZZLE JETTISONED TIME = 390.90	141218.7	1307.130	0.495	0.051	6353.277	141.418 6354.084
SPLASHDOWN TIME = 416.20	141175.7	1307.111	0.495	0.051	6350.922	141.380 6351.729

TABLE 3.10
STS-33 RH SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY			MOMENT OF INERTIA		
		LONG.	LAT.	VERT.	PITCH	ROLL	YAW
PRE-LAUNCH TIME = 0.00	1256025.1	1171.384	0.059	0.006	42389.502	879.649	42390.379
LIFT-OFF TIME = 0.23	1255330.2	1171.515	0.059	0.006	42346.302	878.338	42347.179
INTERMEDIATE BURN TIME = 20.00	1013170.6	1208.341	0.073	0.008	30644.446	760.912	30645.321
INTERMEDIATE BURN TIME = 40.00	792736.1	1231.457	0.093	0.010	21667.162	626.698	21668.031
MAX "Q" TIME = 54.00	662986.9	1228.979	0.111	0.011	17997.742	549.660	17998.605
INTERMEDIATE BURN TIME = 60.00	608331.0	1226.456	0.120	0.013	16599.656	513.597	16600.515
INTERMEDIATE BURN TIME = 80.00	417272.6	1214.597	0.174	0.018	11948.669	380.140	11949.516
MAX "G" TIME = 87.00	353346.2	1213.587	0.205	0.022	10567.208	329.693	10568.051
INTERMEDIATE BURN TIME = 100.00	247943.8	1226.139	0.290	0.031	8573.547	241.007	8574.382
WEB BURN TIME = 111.23	172737.8	1267.708	0.413	0.044	7289.306	172.022	7290.133
END OF ACTION TIME 'INI' = 123.12	144619.1	1314.887	0.492	0.053	6612.251	146.905	6613.074
SEPARATION TIME = 126.20	143923.4	1316.776	0.495	0.053	6578.410	146.427	6579.236
MAX REENTRY "Q" TIME = 321.20	143542.9	1316.747	0.496	0.052	6557.602	146.088	6558.428
NOSE CAP DEPLOYMENT TIME = 351.20	143490.6	1316.729	0.496	0.052	6554.828	146.041	6555.656
DROGUE CHUTE DEPLOYMENT TIME = 351.80	143489.6	1316.728	0.496	0.052	6554.773	146.041	6555.599
FRUSTUM RELEASE TIME = 372.90	143452.8	1316.716	0.496	0.052	6552.810	146.008	6553.637
MAIN CHUTE LINE STRETCH TIME = 374.20	143450.6	1316.715	0.496	0.052	6552.689	146.006	6553.516
MAIN CHUTE 1ST DISREEFING TIME = 384.30	143432.9	1316.709	0.496	0.052	6551.745	145.990	6552.572
MAIN CHUTE 2ND DISREEFING TIME = 390.20	143422.7	1316.706	0.496	0.052	6551.192	145.981	6552.019
NOZZLE JETTISONED TIME = 390.90	141193.3	1305.696	0.495	0.051	6335.324	141.375	6336.130
SPLASHDOWN TIME = 416.20	141150.3	1305.677	0.495	0.051	6332.967	141.337	6333.773

TABLE 3.11

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
STS-33 Left Hand

Event	Weight (lb)			Longitudinal CG (in)		
	Predicted ¹	Actual	Delta	% Error	Predicted ¹	Actual
Pre-Ignition	1,256,049	1,256,049	0	0.00	1,171.216	1,171.216
Liftoff	1,255,414	1,255,356	-58	0.00	1,171.342	1,171.348
Action Time	144,345	144,581	+236	0.16	1,313.212	1,315.655
Separation ²	143,617	143,975	+358	0.25	1,315.166	1,317.334
Nose Cap Deployment	143,034	143,516	+482	0.34	1,315.519	1,317.319
Drogue Chute Deployment	143,033	143,515	+482	0.34	1,315.519	1,317.319
Main Chute Line Stretch	142,994	143,476	+482	0.34	1,315.505	1,317.306
Main Chute 1st Disreefing	142,976	143,458	+482	0.34	1,315.499	1,317.300
Main Chute 2nd Disreefing	142,966	143,448	+482	0.34	1,315.496	1,317.297
Nozzle Jettison	140,737	141,219	+482	0.34	1,305.258	1,307.130
Splash Down	140,694	141,176	+482	0.34	1,305.239	1,307.111

Notes:

1. Based on Mass Properties History Log Space Shuttle 3601007-LH, 5 August 1989 (TWR-17346).
2. The separation longitudinal center of gravity of 1,317.334 is 66% of the vehicle length.

TABLE 3.12
SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
STS-33 Right Hand

Event	Weight (lb)			% Error	Longitudinal CG (in)			
	Predicted ¹	Actual	Delta		Predicted ¹	Actual	Delta	% Error
Pre-Ignition	1,256,025	1,256,025	0	0.00	1,171.384	1,171.384	0.000	0.00
Liftoff	1,255,391	1,255,330	-61	0.00	1,171.511	1,171.515	+0.004	0.00
Action Time	144,320	144,619	+299	0.21	1,312.626	1,314.887	+2.261	0.17
Separation ²	143,591	143,923	+332	0.23	1,314.577	1,316.776	+2.199	0.17
Nose Cap Deployment	143,009	143,491	+482	0.34	1,314.927	1,316.729	+1.802	0.14
Drogue Chute Deployment	143,008	143,490	+482	0.34	1,314.927	1,316.728	+1.801	0.14
Main Chute Line Stretch	142,969	143,451	+482	0.34	1,314.913	1,316.715	+1.802	0.14
Main Chute 1st Disreefing	142,951	143,433	+482	0.34	1,314.907	1,316.709	+1.802	0.14
Main Chute 2nd Disreefing	142,941	143,423	+482	0.34	1,314.904	1,316.706	+1.802	0.14
Nozzle Jettison	140,711	141,193	+482	0.34	1,303.818	1,305.696	+1.878	0.14
Splash Down	140,668	141,150	+482	0.34	1,303.833	1,305.677	+1.844	0.14

Notes:

1. Based on Mass Properties History Log Space Shuttle 3601007-RH, 5 August 1989 (TWR-17347).
2. The separation longitudinal center of gravity of 1,316.776 is 66% of the vehicle length.

TABLE 3.13

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS

STS-33 LEFT HAND

Item	Minimum	Maximum	Predicted ³	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,076	149,539	149,539	0	0.00	1
Propellant	1,104,714		1,106,493	1,106,493	0	0.00	1
Usable			1,105,634	1,105,880	+246	0.02	2
To Liftoff			535	592	+57	9.63	
Liftoff to Action			1,105,099	1,105,288	+189	0.02	2
Unusable			859	613	-246	40.13	
Action to Separation			669	546	-123	22.53	
After Separation			190	67	-123	183.58	
Slag			1,518	2,000	+482	24.10	2

Notes:

1. Requirement per CPW1-3600A, Addendum G, Part I, (RSRM CEI Specification).
2. Slag included in usable propellant, liftoff to action.
3. Based on 5 August 1989, Mass Properties History Log Space Shuttle 360L007-LH (TWR-17346).

TABLE 3.14

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS

STS-33 RIGHT HAND

Item	Minimum	Maximum	Predicted ³	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,076	149,538	149,538	0	0.00	1
Propellant	1,104,714		1,106,487	1,106,487	0	0.00	1
Usable			1,105,629	1,105,811	+182	0.02	2
To Liftoff			535	594	+59	9.93	
Liftoff to Action			1,105,094	1,105,217	+123	0.01	2
Unusable			858	676	-182	26.92	
Action to Separation			668	635	-33	5.20	
After Separation			190	41	-149	363.41	
Slag			1,518	2,000	+482	24.10	2

Notes:

1. Requirement per CPWL-3600A, Addendum G, Part I, (RSRM CEI Specification).
2. Slag included in usable propellant, liftoff to action.
3. Based on 5 August 1989, Mass Properties History Log Space Shuttle 360L007-RH (TWR-17347).

FIGURE 1.1
RSRM PROPELLANT GRAIN DESIGN CONFIGURATION

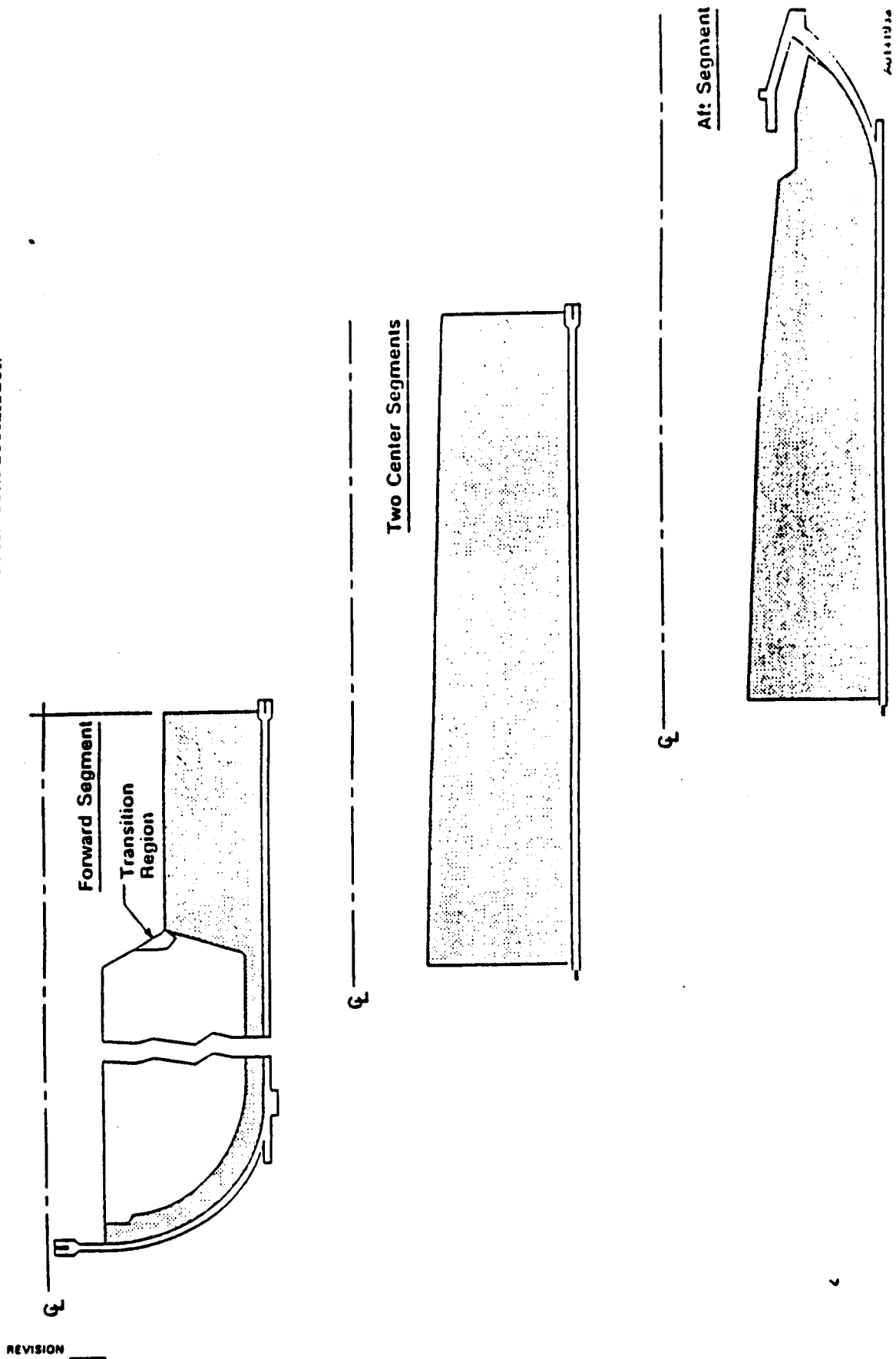


FIGURE 2.1
 RSRM-7 RECONSTRUCTED VACUUM THRUST VS. TIME
 AT DELIVERED CONDITIONS (71 deg F)

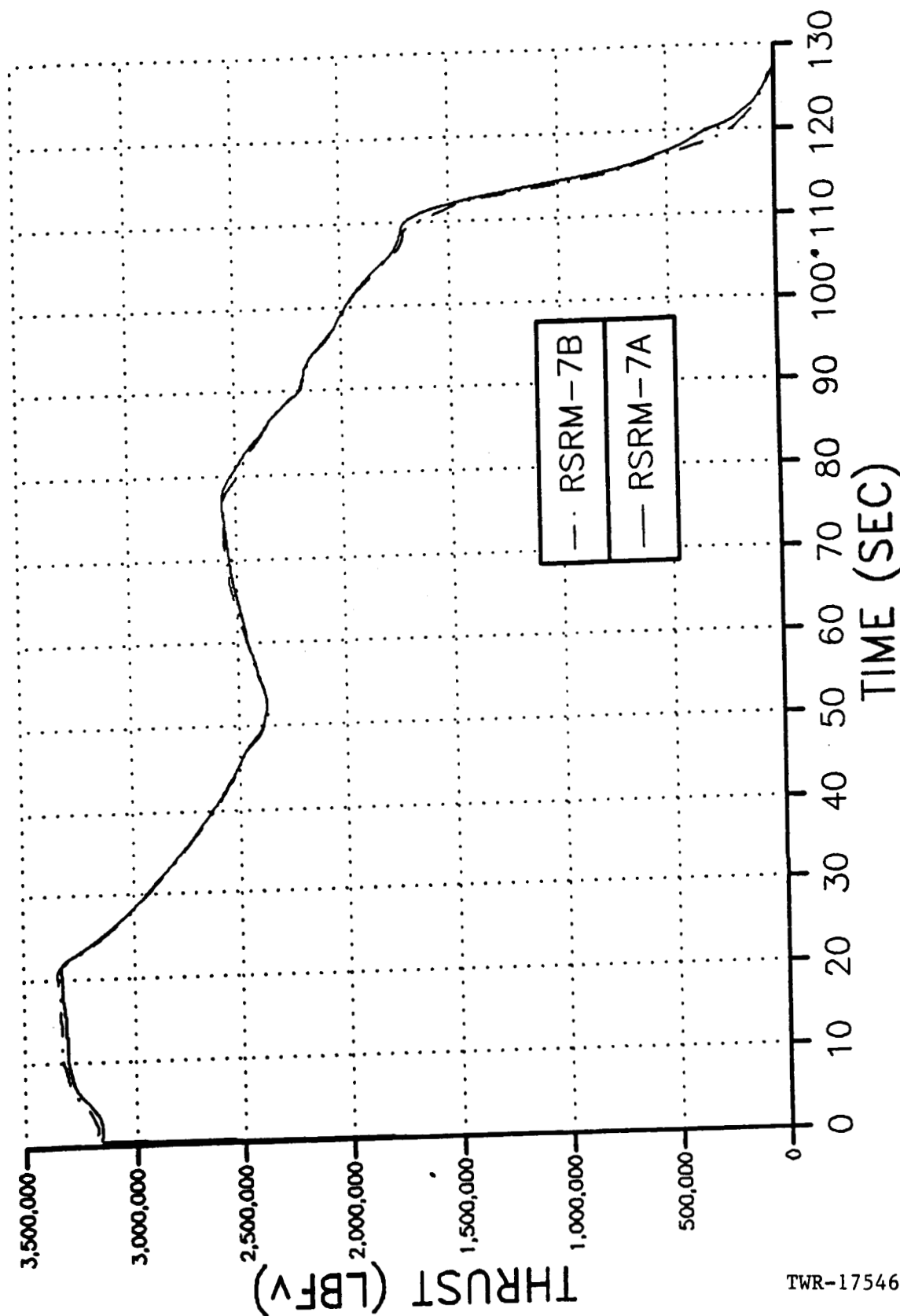


FIGURE 3.1
 RSRM-7A PREDICTED VS. RECONSTRUCTED
 VACUUM THRUST

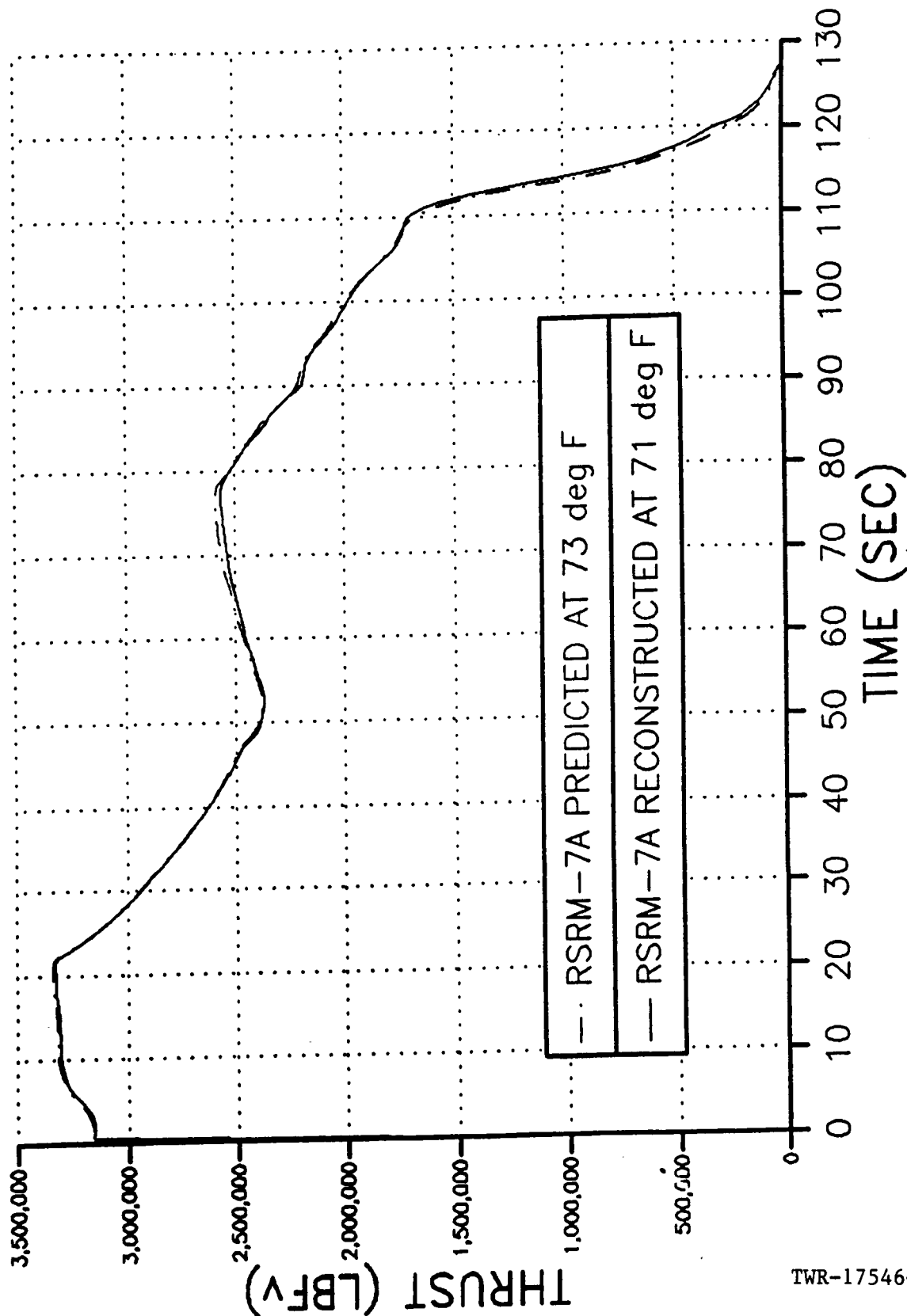


FIGURE 3.2
RSRM-7B PREDICTED VS. RECONSTRUCTED
VACUUM THRUST

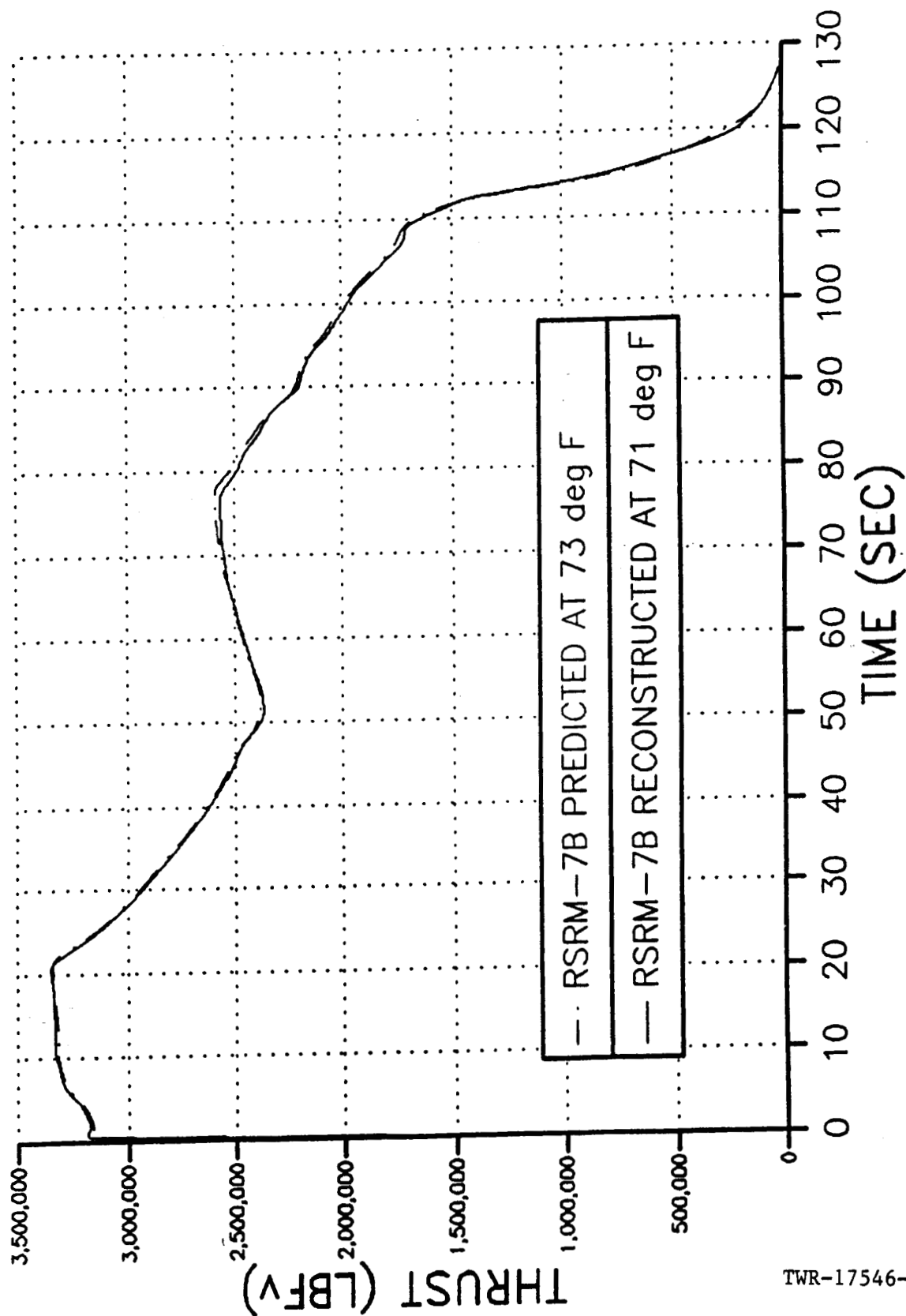
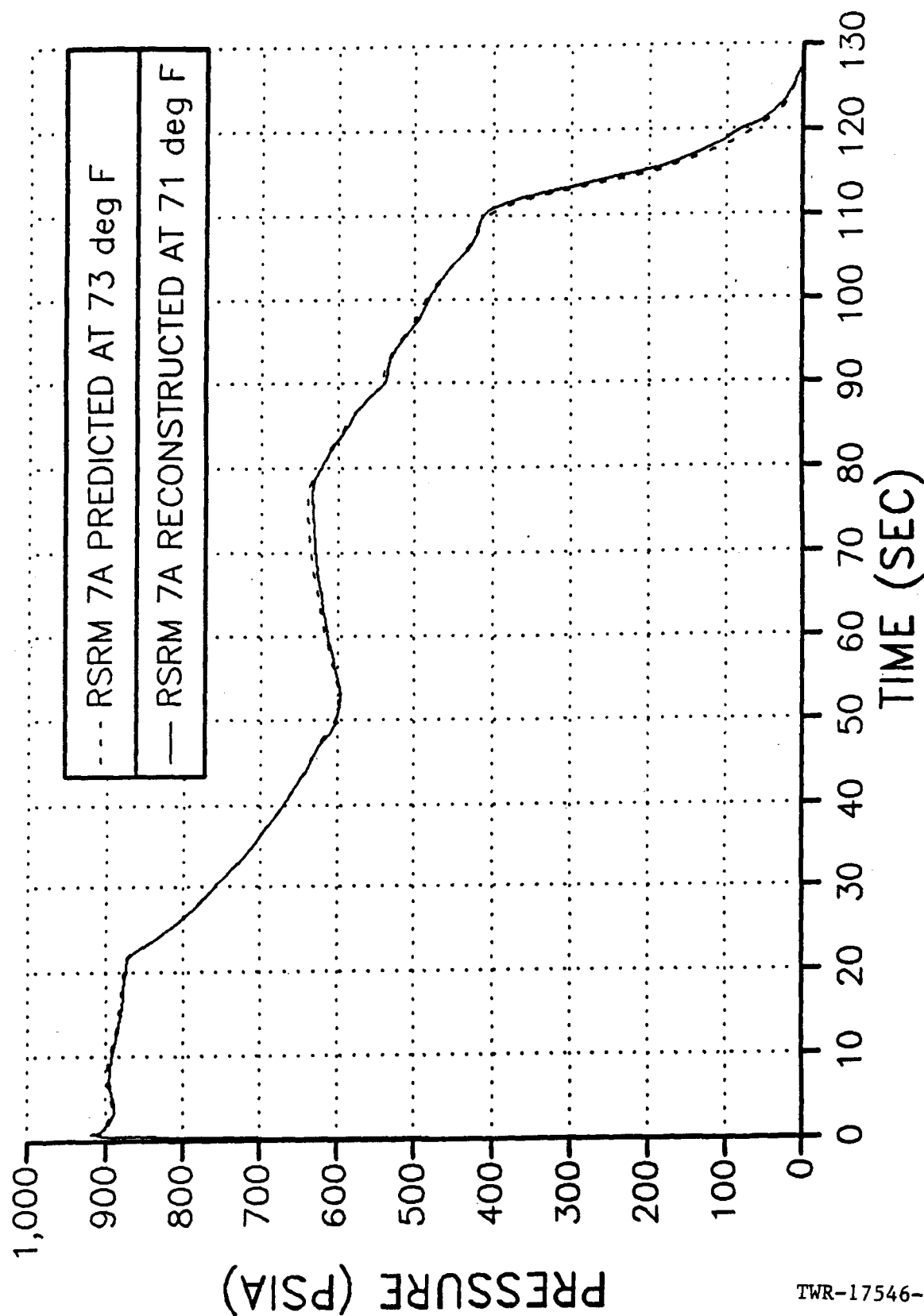


FIGURE 3.3
RSRM-7A PREDICTED VS. RECONSTRUCTED
CHAMBER PRESSURE



TWR-17546-10

FIGURE 3.4
RSRM-7B PREDICTED VS. RECONSTRUCTED
CHAMBER PRESSURE

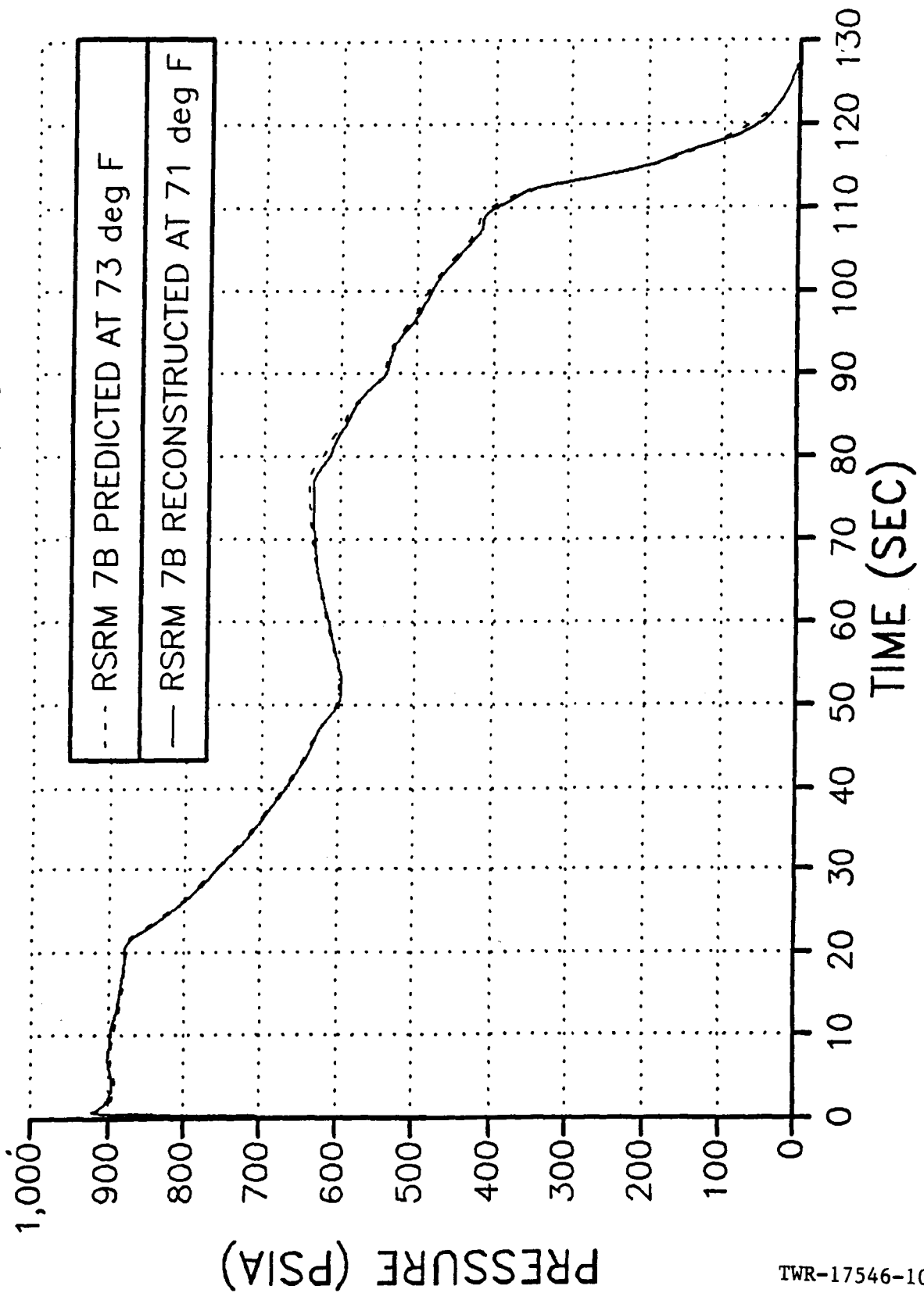


FIGURE 3.5
 RSRM-7A PERFORMANCE COMPARED TO
 HPM/RSRM POPULATION NOMINAL

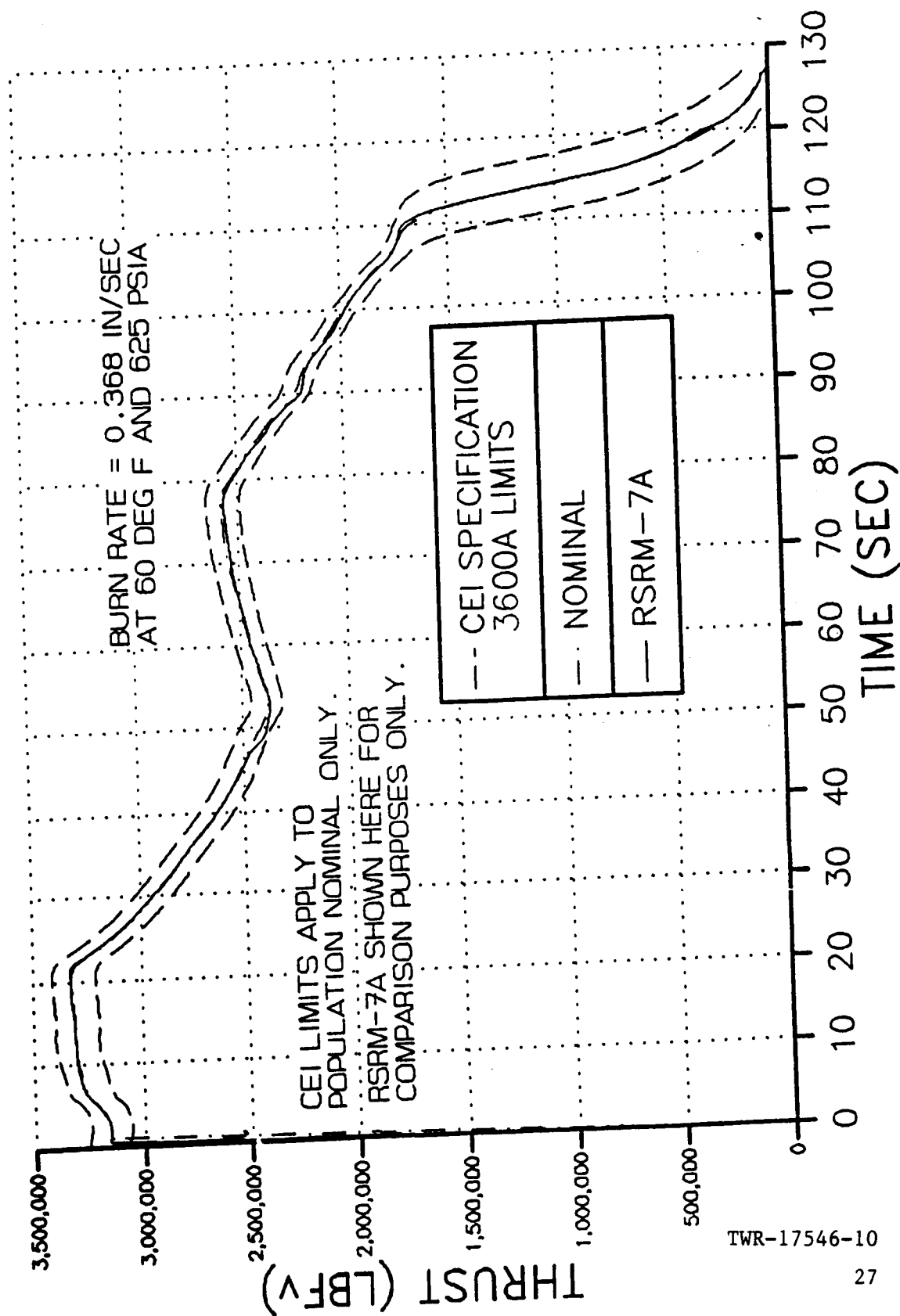


FIGURE 3.6
 RSRM-7B PERFORMANCE COMPARED TO
 HPM/RSRM POPULATION NOMINAL

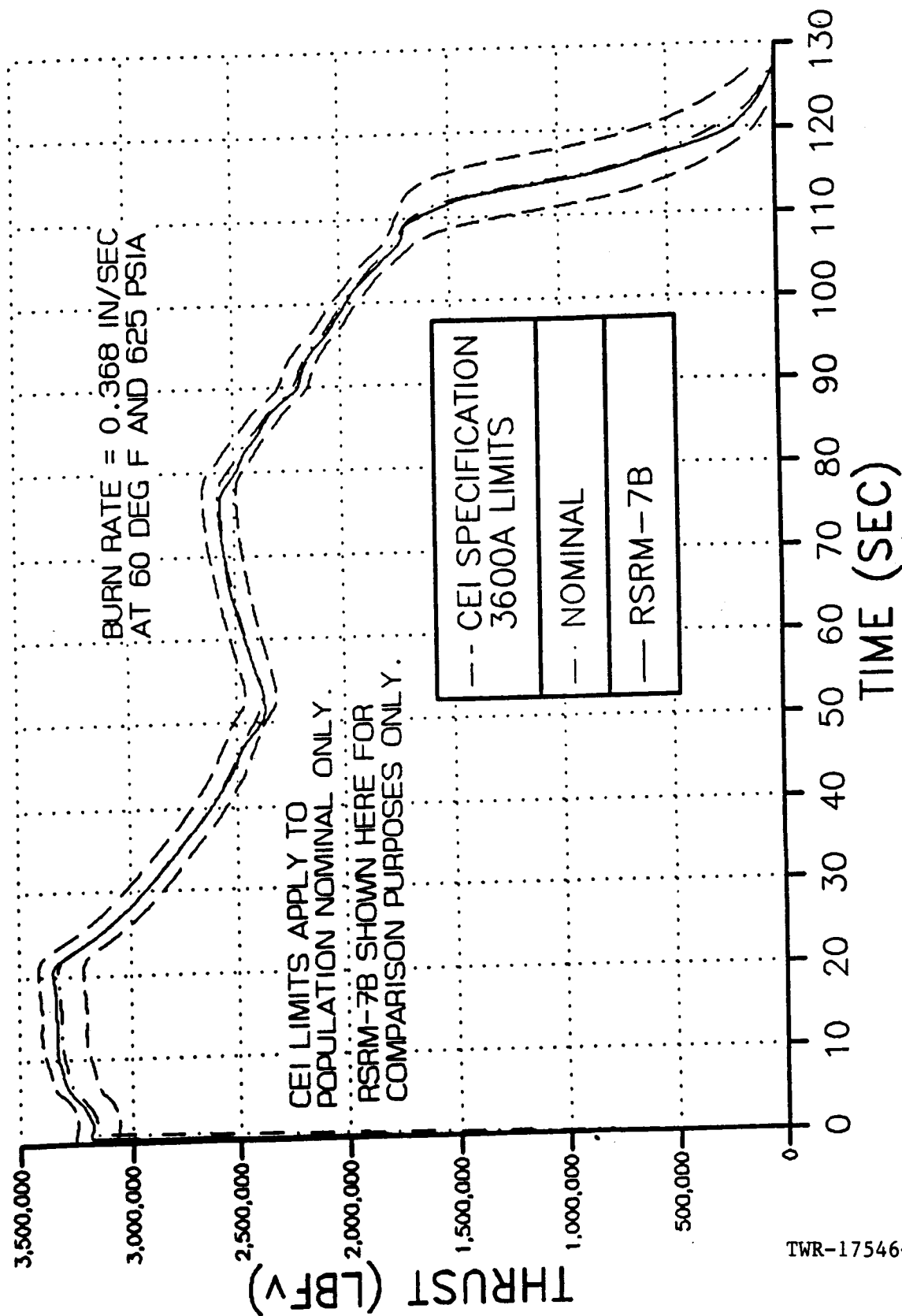
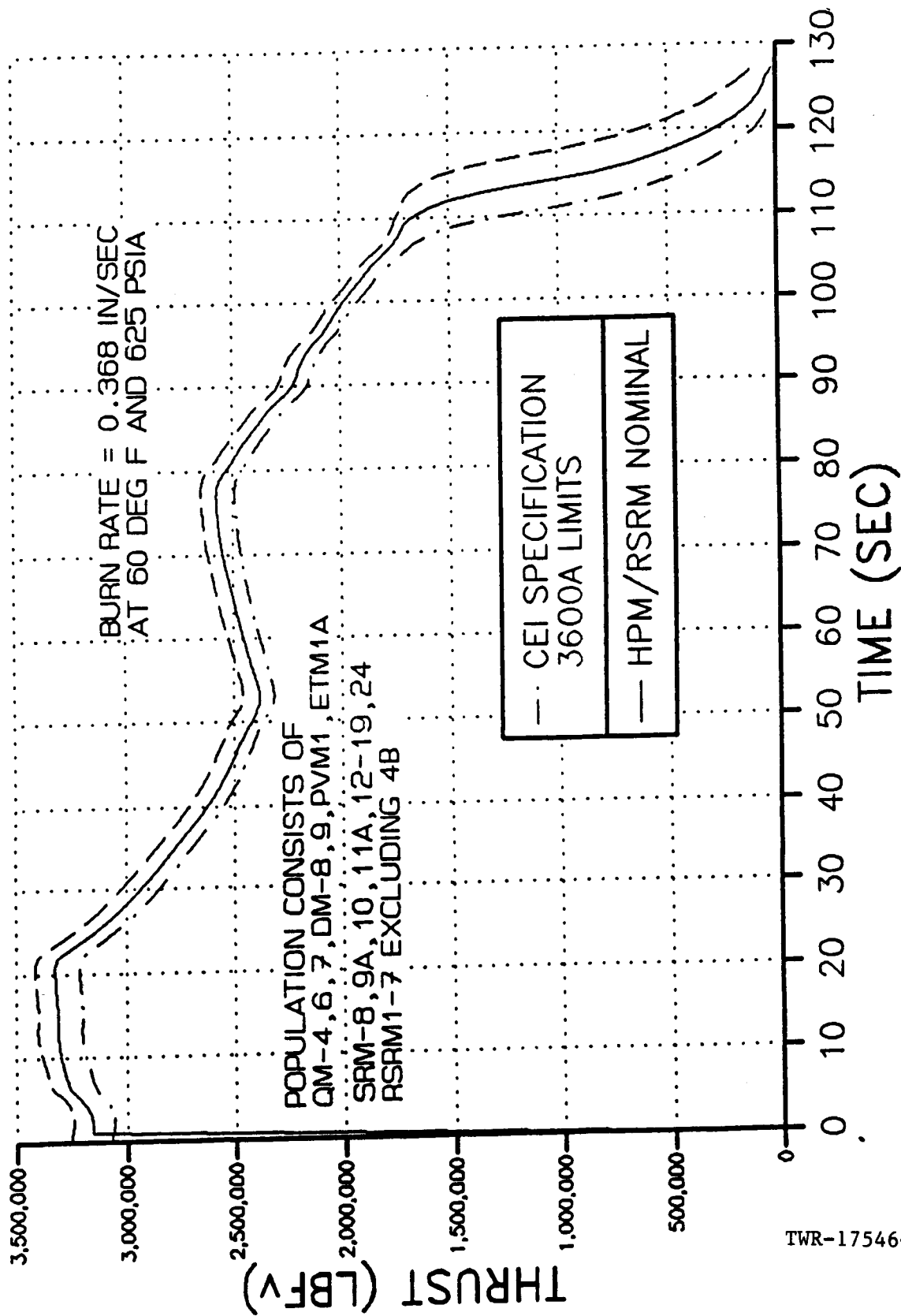


FIGURE 3.7
 RSRM/HPM NOMINAL VACUUM THRUST COMPARED
 TO CEI SPECIFICATION LIMITS



TWR-17546-10

Figure 3.8
RSRM-7 INSTANTANEOUS
STEADY STATE THRUST IMBALANCE

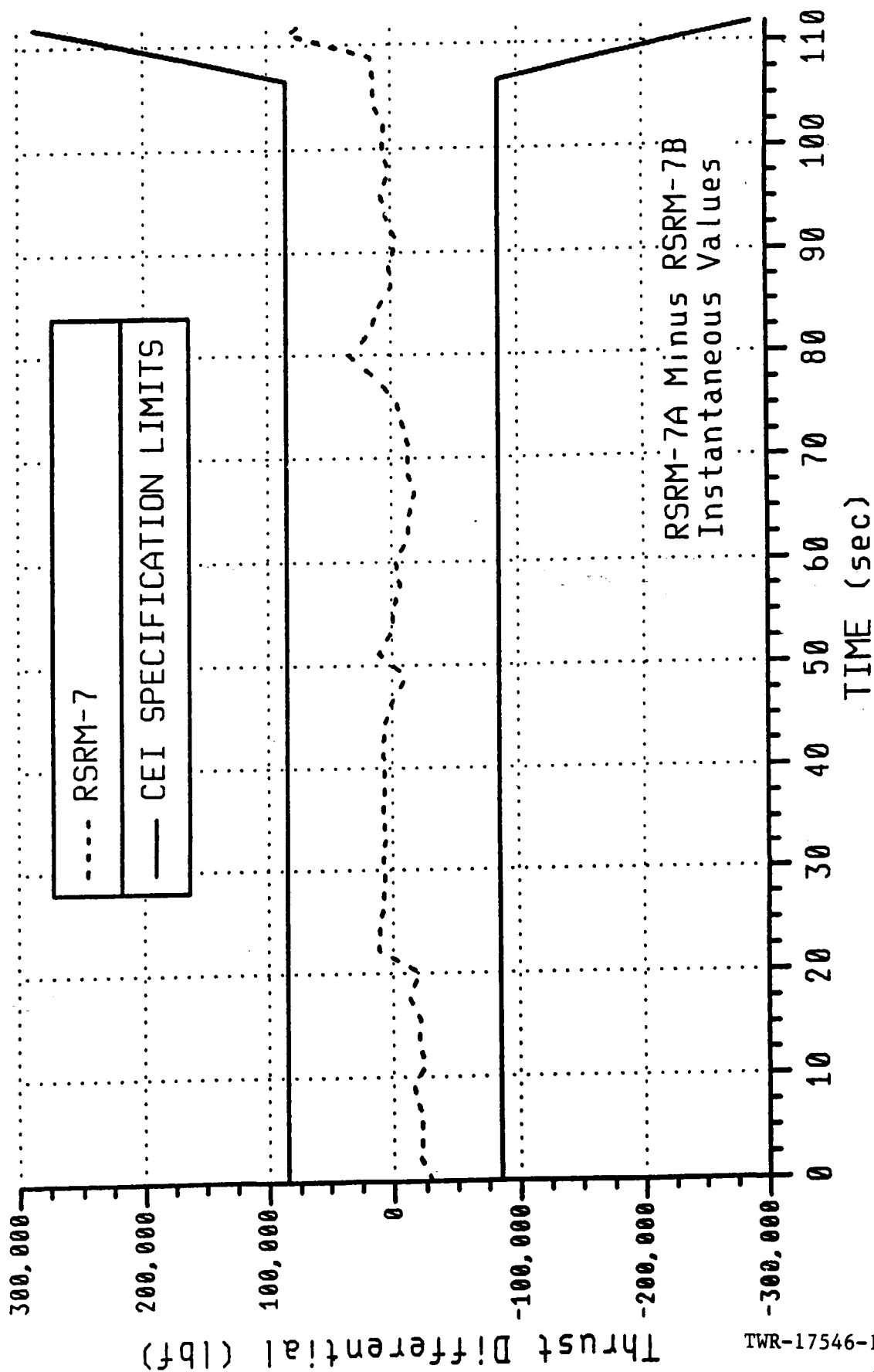


Figure 3.9
RSRM-7 4-SECOND AVERAGE
STEADY STATE THRUST IMBALANCE

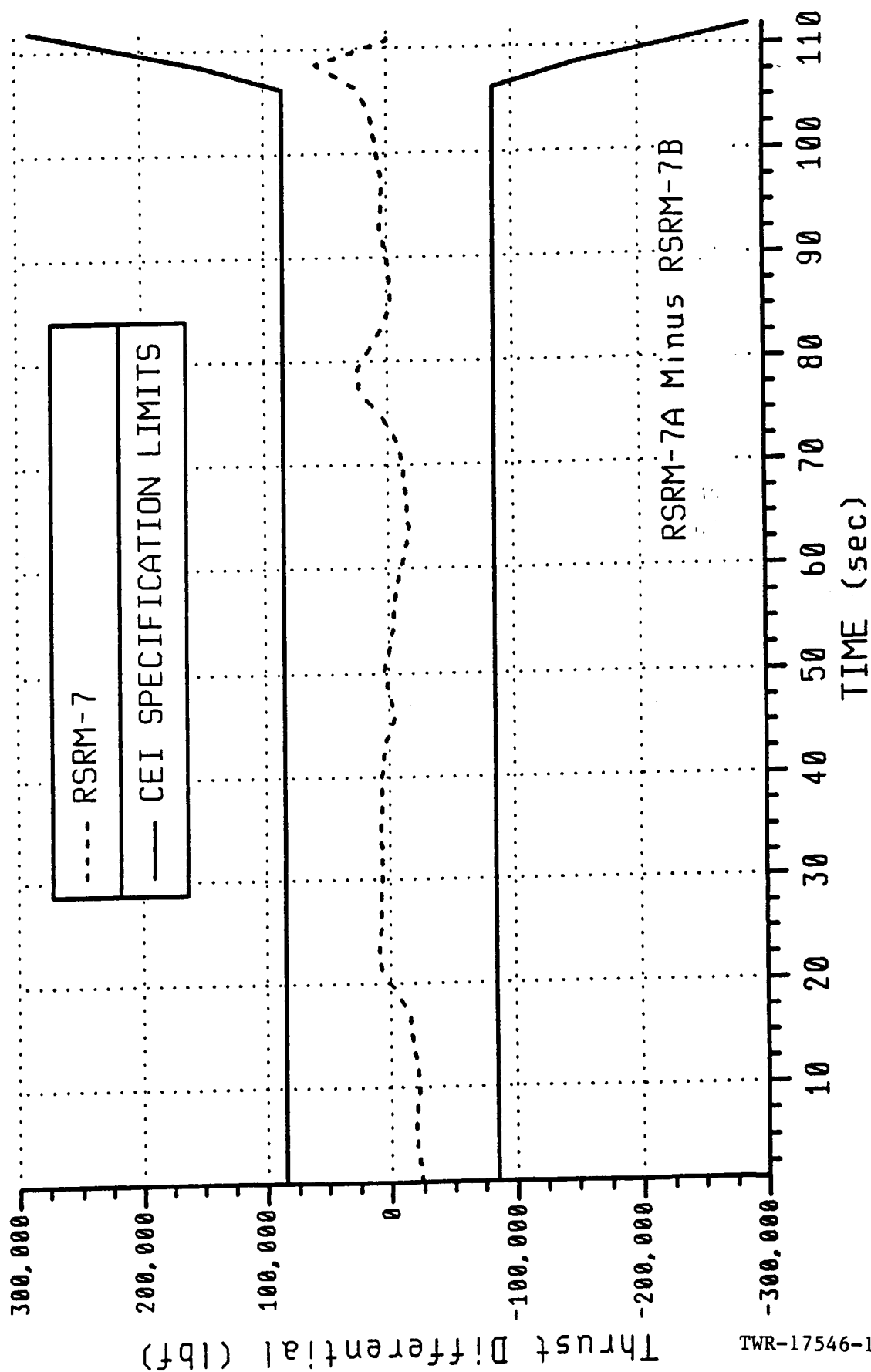


Figure 3.10
RSRM-7 TAILOFF THRUST IMBALANCE

